OUTER PLANETS
PROGRAM DESCRIPTION

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OUTER PLANETS PROGRAM DESCRIPTION

1. Introduction

This document contains an overview of the Outer Planets/Solar Probe (OP/SP) Project and describes the time frame, project management environment, fiscal policies, and spacecraft development and flight operations environments in which the selected science teams will function.

It is important to note that the OP/SP Project is still in the formative stage, and it is to be expected that evolution will occur in response to changes in the fiscal climate, technology developments, and personnel changes. NASA has not committed to this Project, nor these missions, nor to any specific schedule, launch vehicle, power source, Project budget, or funding profile.

The word "project" means the Outer Planets/Solar Probe Project at NASA's Jet Propulsion Laboratory encompassing the three missions, Europa Orbiter, Pluto-Kuiper Express, and Solar Probe. "Mission" refers to one of the three above missions. "Spacecraft" is synonymous with "flight system" including all launched hardware and software and generally refers to the spacecraft for a specific mission. The terms "Europa Orbiter," "Pluto-Kuiper Express," and "Solar Probe" may be used to refer either to the spacecraft itself or to the respective mission.

2. Project overview and schedule

The first three Outer Planets/Solar Probe missions are being developed and implemented as a single project. Presently the first mission is planned to be Europa Orbiter, launching in 2003, followed by Pluto-Kuiper Express launching in 2004, and Solar Probe in early 2007.

Though ultimately targeted for three very different destinations, all three missions will utilize Jupiter flybys to reduce required launch vehicle size. The three spacecraft will share nearly all their avionics in common, along with some telecommunications and propulsion components. Core software will be common, including that controlling generic spacecraft functions, and the three missions will be operated during their long cruise periods by a common team. These functions of interplanetary missions typically add up to a large fraction of a mission's total cost.

Most of the common components of these missions are being developed and qualified by the Deep Space System Technology Program's X2000 First Delivery Project. The three OP/SP missions represent three of the five primary customers for this First Delivery Project; the other two customers are the New Millennium Deep Space-4/Champollion comet mission and the Mars Sample Return.

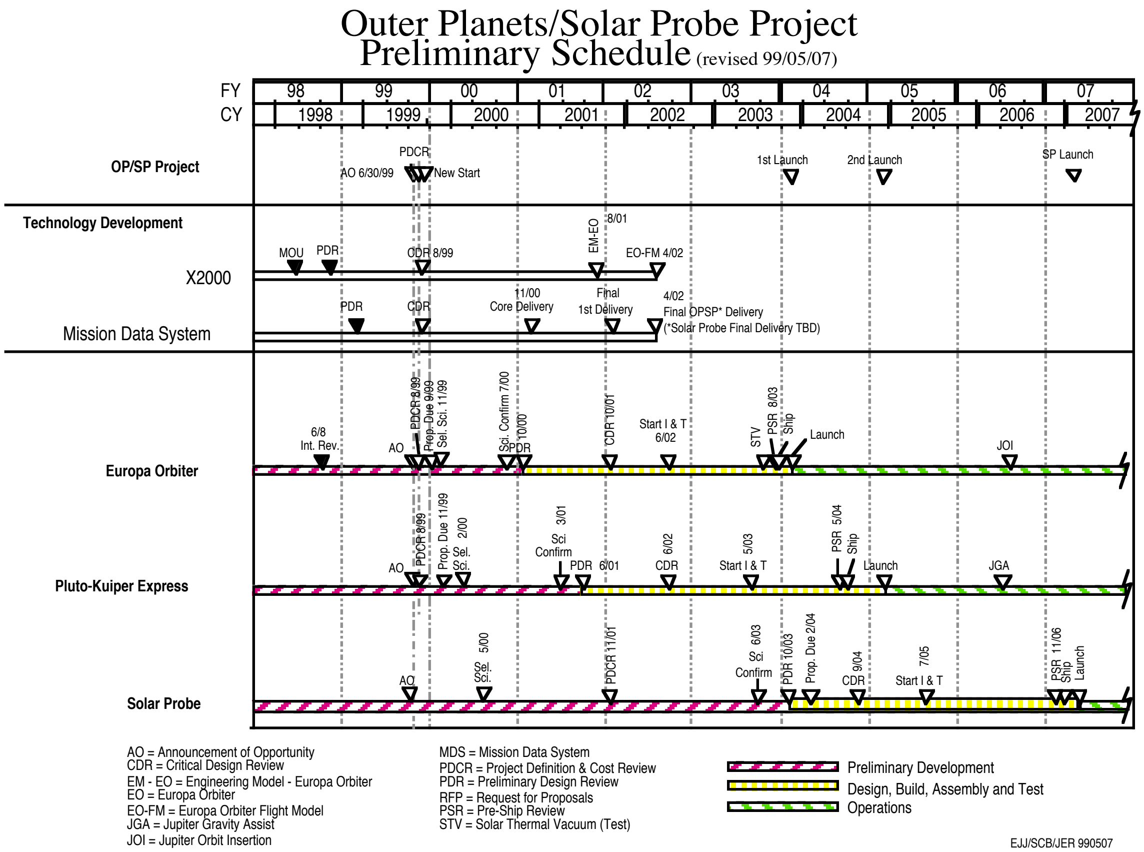

Figure 1. Outer Planets/Solar Probe Preliminary Schedule

Some aspects of the three missions are clearly unique: most notably the science and instrumentation, trajectories, propulsion, radiation shielding for the Europa Orbiter, and thermal shielding for Solar Probe. Launch systems will also differ, depending on availability and performance. In spite of these differences, a single team will complete preliminary design of the three flight systems using largely X2000 hardware and software. A single trajectory/mission design team will develop all three missions, as will a single launch system team. As each mission in turn enters detailed design, a dedicated mission implementation team will be formed, with the leader for each such team reporting to the project manager. There will be sharing of some individuals across more than one mission team, both to enhance communication of common issues and to smooth work loading. Members of the selected science investigation teams are expected to become part of the flight system and mission/trajectory design teams. After launch, a single, unified flight operations team will operate the flight systems.

The OP/SP Project schedule is shown in Figure 1. Preliminary launch and encounter milestones are shown in Figure 2. The Europa Orbiter is to launch in November 2003, and Pluto-Kuiper Express in December 2004; for the purpose of this AO, these dates should be

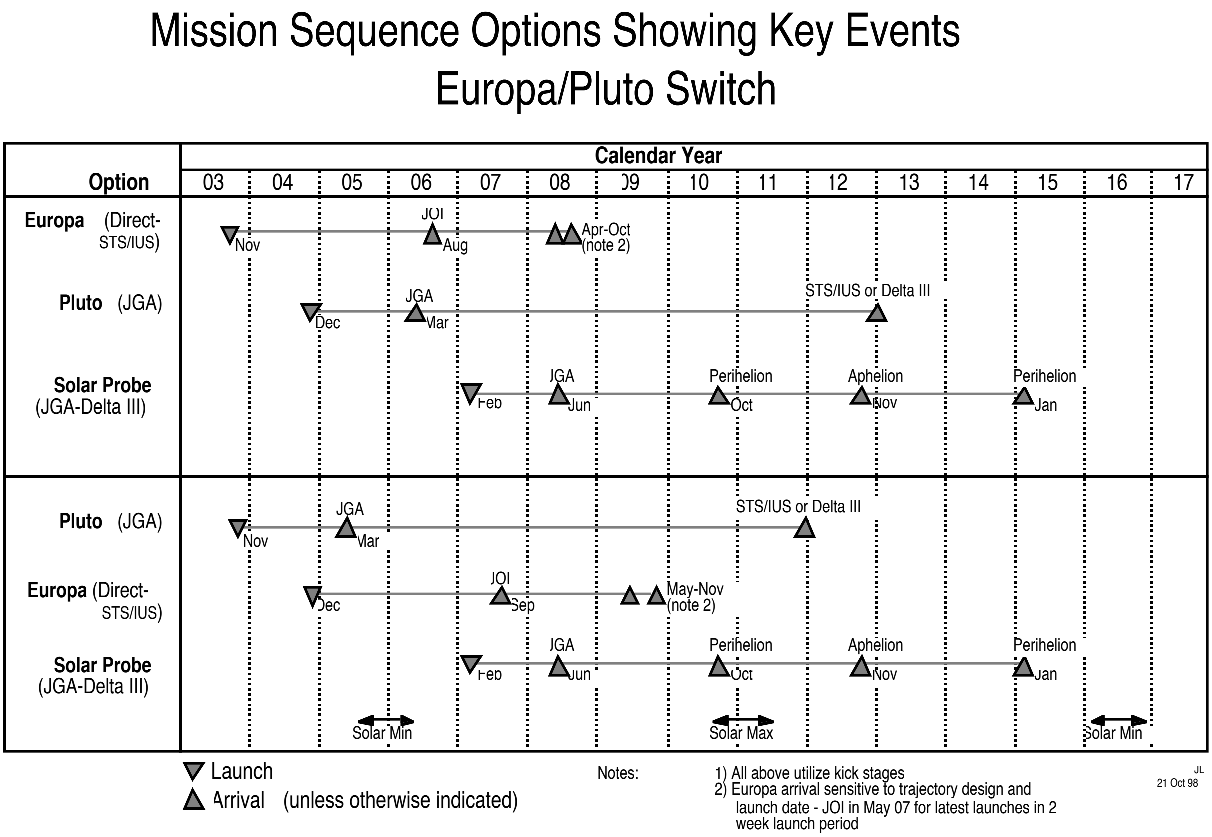

Figure 2. Mission Sequence Options, Showing Key Events

assumed. Two decision "gates" are planned. On or before the date of each gate, the readiness of Europa Orbiter for its 2003 launch will be evaluated. Gate 1 follows the OP/SP Project Definition and Cost Review (PDCR) and the X2000 First Delivery Project Critical Design Review (CDR) around December 1999. Gate 2 is in August 2000. If a decision is made that Europa Orbiter will not be ready for the 2003 launch, it will be delayed to 2004. If this decision is made at Gate 1, the Pluto-Kuiper Express launch date may be moved from December 2004 to November 2003, as shown in Figure 2.

3. Project organization

Overall project leadership and coordination are provided by the Project Manager and Project Office staff. The project is organized as shown in Figure 3. In the organization chart, the upper row can be considered staff positions, and the lower row line functions. The Chief Scientist is a member of the Project Office staff, is appointed by the Project Manager and reports to the Project Manager.

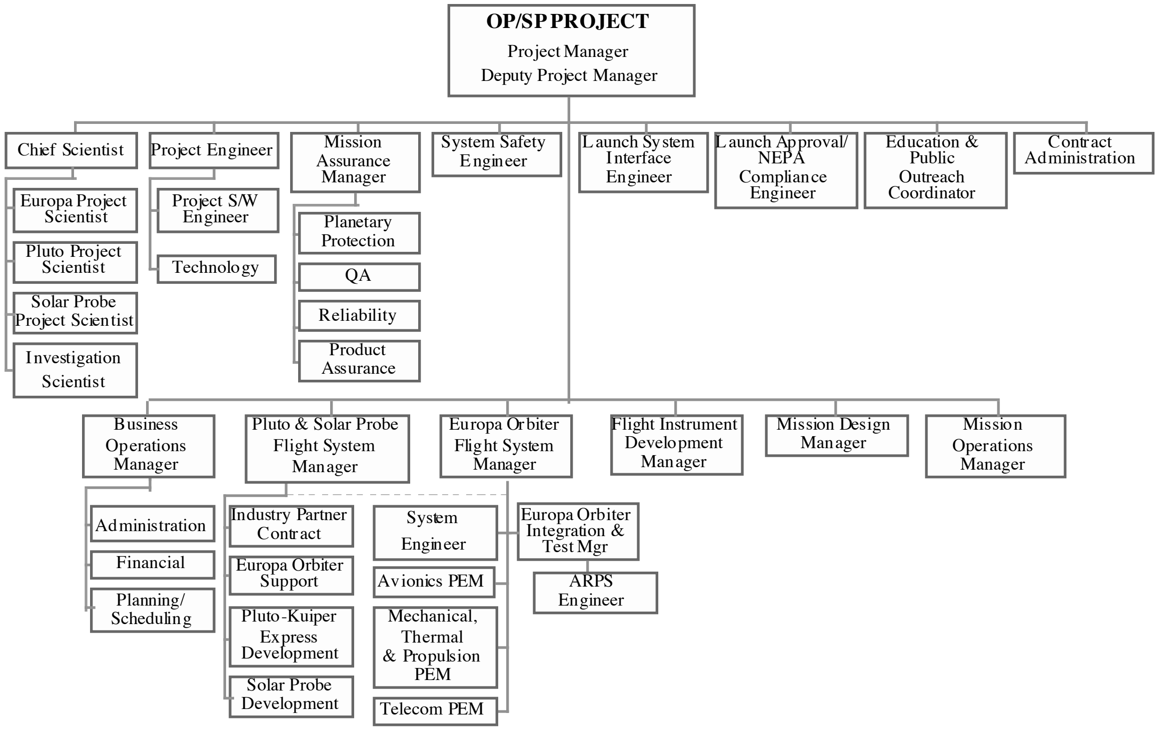

Figure 3. Organization Chart for the Outer Planets/Solar Probe Project.

4. Mission rationale

4.1 Europa

The Europa Orbiter mission should be seen in the context of a broader solar system exploration strategy. The recently developed Solar System Exploration Roadmap identifies several major themes or quests for future exploration and campaign strategies for implementing them. One of these campaigns, Pre-biotic Chemistry in the Outer Solar System, is concerned with the quest to understand the origins of life and the environments that may sustain or give rise to it. Over the last thirty years, data from earth-based telescopes, the Voyager encounters in 1979, and the ongoing Galileo mission have all pointed toward Europa as an exciting target in this quest. These data, combined with theoretical arguments, suggest that Europa has had a liquid water ocean some 100-150 km deep under several kilometers of exterior ice, and further, that tidal energy from Jupiter may be sufficient to maintain that ocean to the present day.

Over the same period that our knowledge of Europa was growing, exploration of Earth's deep ocean environment was revealing remarkable new environments and biota that have changed our view of the conditions needed to sustain life and possibly to form it. Deep mid-ocean ridge hydrothermal vent systems are associated with a rich variety of life forms, some of which exist at previously unheard of temperatures and in the absence of light and oxygen, drawing their energy from chemical reactions in volcanic fluids. Some of these organisms may be similar to the first life to emerge on the Earth. The possibility that Europa may have had, and may still have, an extraterrestrial ocean environment similar to Earth's mid-ocean hydrothermal vent systems is one of the fundamental rationales for conducting further exploration of Europa.

The specific rationale for the proposed 2003 Europa Orbiter mission flows from the gaps in our current knowledge and the desire to lay the groundwork for more extensive exploration of Europa's putative ocean. While the current data are extremely exciting, they are not sufficient to establish the presence on an ocean on Europa unambiguously at the present time. The need for, and style of, further exploration hinges on an answer to this question. In addition, in the event that an ocean is present, future missions will need far more detailed information on surface and sub-surface properties of the ice layer to plan for effective exploration. The several science strategy working groups that have considered this problem have explored numerous possible mission types and combinations. Even with advanced instrumentation, flyby type missions, whether distant, rapid flybys like Voyager's or frequent close encounters similar to the Galileo mission, lack the capability for in-depth exploration needed to make the next major advance in understanding Europa. These advisory groups concluded that an orbiting mission is a primary requirement for the next phase of Europa exploration.

4.2 Pluto

Ten years after Voyager 2 flew past Neptune, Pluto remains the only planet in our Solar System that has not been visited by spacecraft. Perched on the outer edge of the classical realm of the planets, and just within the Kuiper Belt of primitive material remaining from the Solar System's formation, Pluto and its moon Charon hold chemical clues to the conditions at the interface between the protoplanetary disk itself and the precursor molecular cloud. Their small size makes it likely that these clues are at least partially preserved in the molecular composition of their ices, unlike the material in the vastly more massive giant planets. However, Pluto's large size (and high albedo) relative to other icy bodies has made it accessible to study from Earth in sufficient detail to know that it possesses a surface containing frosts of very volatile species that also occur in comets and that are confirmed or suspected to be present in molecular clouds. The density of Pluto is consistent with an internal mixture of rock and ice that is close to the value predicted for primitive Solar System material.

Pluto is known to have an atmosphere, and one whose energy balance is unique in the Solar System. The atmosphere is almost certainly dynamic and transient and will decrease in mass or collapse as Pluto continues to retreat from its 1989 closest approach to the Sun. Pluto's small size means the atmosphere must be escaping the planet at a rapid rate making it intermediate in stability between those of comets and those of larger planets.

What we know of Pluto is enough to make this smallest planet intriguing, but much remains unknown. We do not know how the ices are distributed across Pluto's surface nor how geology has shaped its surface. Many trace species beyond those detected on the surface undoubtedly exist. The nature of the dark material on Pluto is unknown, in particular whether it is organic material processed by cosmic rays or sunlight, or simply silicates. We only inferentially understand the structure of the atmosphere, and available models only hint at its composition and dynamics. We do not know how the atmosphere will respond to the decrease of insolation as Pluto recedes from the Sun. We suspect that Pluto does not have a significant intrinsic magnetic field, but even a small magnetization would suffice to stand off the solar wind. The inferred atmospheric escape rates suggest a comet-like interaction with the solar wind if such a field is not present - an interaction possibly unique in the Solar System.

We know far less about Charon, including its surface appearance, compositional relationship to Pluto, and origin. The surfaces of both Pluto and Charon might show the scars of their early history in terms of craters and tectonics induced by tides or impacts, but we cannot tell without very high-resolution imagery. The close correspondence in size of Pluto and Charon (closer than that of any other planet-moon system) is also a mystery.

Many of the questions posed about Pluto and Charon (discussed in detail in the Pluto-Kuiper Express Science Definition Team Report) can only be addressed by a spacecraft mission that brings advanced instruments close to the two bodies. The level of knowledge of all other planets and their moons increased enormously through visits by spacecraft, and it is well understood, particularly after *Voyager* and *Magellan*, how essential spacecraft exploration is to understanding the nature of the Solar System.

The recent discovery of many objects beyond Neptune and Pluto in orbits corresponding to the predicted Kuiper Belt has opened another exciting dimension for this mission of exploration. Kuiper Belt objects are likely to be remnants of Solar System formation, holding clues to the birth of the planets in stable and well-defined orbits that have never taken them close to the Sun. A possible extension beyond Pluto to visit one or more of these objects would be an extraordinary complement to a Pluto flyby, such that the whole suite of outermost primitive bodies from comet-sized objects to planets is reconnoitered. It may be possible to conduct a systematic search and inventory of Kuiper Belt objects near the flight path to count and characterize bodies smaller than can be observed from Earth. Knowledge of the size and mass distribution of objects in the Kuiper Belt would be of great value in developing theoretical models of the evolution and destiny of the solar system.

Beyond the scientific value of a Pluto mission, the technological challenge fits well NASA's intention to develop new, low-cost spacecraft employing advanced technologies. These missions are essential if the nation is to continue its vigorous program of scientific exploration of the cosmos under the severe funding limitations that NASA faces in the foreseeable future. Programs to develop and implement technologies to achieve these goals, *X2000* and *New*

Millennium, are also in progress. A mission to fly past Pluto and Charon and obtain a comprehensive set of measurements, a *"Pluto-Kuiper Express",* is well matched to exercising the capabilities developed and proven by the *X2000* and *New Millennium* programs.

The Pluto-Kuiper Express mission responds to political and emotional imperatives regarding space exploration. Pluto as a place sparks the imagination of the public, and the concept of a mission to the Solar System's most distant planetary outpost has demonstrated high public appeal. If successfully executed, the mission will assure the United States of continued access to the deep outer Solar System during difficult financial times.

4.3 Solar Probe

The solar wind is highly significant in astrophysics since it is an example of all stellar winds and the only one that can be investigated in detail and *in-situ*. The solar wind is the expanding, extended ionized atmosphere in the magnetic field of the Sun that fills all of interplanetary space. It therefore controls plasma environments in the solar system, such as the magnetospheres of the Earth and other planets and comet tails, and modifies the surfaces of small, unmagnetized bodies. The solar wind also modulates the penetration of cosmic rays from the galaxy into the solar system and onto the Earth. It interacts with the local interstellar gas and magnetic field in a complex boundary region thought to be about 100 AU from the Sun. Fast objects and thin upstream shockwaves come from the Sun, propagating through the solar wind, and result in magnetic storms and auroras on Earth.

In the 1970s, it was found that the solar wind is organized into distinct high-speed (~800 km/sec) and low-speed (~400 km/sec) components. The high-speed wind is notable for the steadiness of its properties, especially its composition, while the low-speed wind is variable and has a filamentary structure. While the properties of the fast and slow solar wind in interplanetary space are well established, the nature of their source regions is poorly understood. To date there has been no space mission to explore *in situ* the region near the Sun. The Solar Probe Mission is designed to perform the first exploration of the region very near the Sun where the solar wind originates.

Solar Probe will complement Ulysses, Solar Heliospheric Observatory (SOHO), and Transition Region and Coronal Explorer (TRACE) by flying perpendicular to the plane of the ecliptic and inside the solar corona. Because of this close encounter, it can measure particles and fields more than an order of magnitude closer to their source than has ever been done before. With relatively small remote imagers, it can measure the photosphere magnetic field, velocities, and temperatures in the polar regions at spatial resolutions that will never be possible to achieve by observations near the plane of the ecliptic. Solar Probe will create a 3-dimensional map of the entire corona for the first time.

Solar Probe will directly measure the entire polar cap field as well as samples of limited regions with a resolution of 75 km at the poles and half that near the ecliptic plane. By comparison with magnetograms from the ecliptic plane observations, it will be possible for the first time to achieve calibration of the ground- and Earth-orbiting magnetographs.

Solar Probe will fly directly through the polar cap region and polar plumes at altitudes of 7 to 5 R_S. Plasma field and plasma wave measurements with a cadence of 10^{-2} s will give spatial resolution of ~1.5 km.

The Solar Probe trajectory affords a unique opportunity to produce images of the electron-scattered, K corona at visible wavelengths. The spacecraft passes through structures that previously could be viewed only from afar. The steadily varying perspective of all-sky images taken throughout the encounter will allow reconstruction of the global structures of the inner corona. The polar view will give us a direct observation of the longitudinal structure of the solar corona for the first time. High-resolution observations will allow direct imaging of filamentary coronal structures for the first time.

These few examples show that Solar Probe will be able to resolve questions that have only recently arisen in NASA/ESA missions. As the measurements from SOHO and TRACE are more fully understood, they will raise further questions that only the Solar Probe can answer because of its high spatial resolution, *in situ* trajectory, and polar perspective.